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Standardized model of porcine resuscitation using a custom-made resuscitation board results in optimal hemodynamic management

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ABSTRACT

Aim: Standardized modeling of cardiac arrest and cardiopulmonary resuscitation (CPR) is crucial to evaluate new treatment options. Experimental porcine models are ideal, closely mimicking human-like physiology. However, anteroposterior chest diameter differs significantly, being larger in pigs and thus poses a challenge to achieve adequate perfusion pressures and consequently hemodynamics during CPR, which are commonly achieved during human resuscitation. The aim was to prove that standardized resuscitation is feasible and renders adequate hemodynamics and perfusion in pigs, using a specifically designed resuscitation board for a pneumatic chest compression device.

Methods and results: A "porcine-fit" resuscitation board was designed for our experiments to optimally use a pneumatic compression device (LUCAS® II, Physio-Control Inc.), which is widely employed in emergency medicine and ideal in an experimental setting due to its high standardization. Asphyxial cardiac arrest was induced in 10 German hybrid landrace pigs and cardiopulmonary resuscitation was performed according to ERC/AHA 2015 guidelines with mechanical chest compressions. Hemodynamics were measured in the carotid and pulmonary artery. Furthermore, arterial blood gas was drawn to assess oxygenation and tissue perfusion.

The custom-designed resuscitation board in combination with the LUCAS® device demonstrated highly sufficient performance regarding hemodynamics during CPR (mean arterial blood pressure, MAP 46 ± 1 mmHg and mean pulmonary artery pressure, mPAP of 36 ± 1 mmHg over the course of CPR). MAP returned to baseline values at 2 h after ROSC (80 ± 4 mmHg), requiring moderate doses of vasopressors. Furthermore, stroke volume and contractility were analyzed using pulse contour analysis (106 ± 3 ml and 1097 ± 22 mmHg/s during CPR). Blood gas analysis revealed CPR-typical changes, normalizing in the due course. Thermodilution parameters did not show persistent intravascular volume shift.

Conclusion: Standardized cardiopulmonary resuscitation is feasible in a porcine model, achieving adequate hemodynamics and consecutive tissue perfusion of consistent quality.

1. Introduction

Cardiac arrest (CA) persists as one of the leading causes of death in modern medicine despite efforts to improve cardiopulmonary resuscitation (CPR) quality [1-4]. In the United States, about 326,000 people per annum suffer from out-of-hospital cardiac arrest (OHCA) [5]. Despite many interventions and trials, human long-term outcome following CA has not improved significantly [3,6-9]. Many bench-to-bedside approaches to test new interventions or drugs rely on reproducible animal models [10]. In resuscitation research, porcine models are most widely used with 52% of all experimental animal models [11]. Pigs are favored as an almost-ideal model due to their highly human-like physiology [10], studying interventions with results being well transferable to humans. Recent literature states that chest compressions are the most essential part of successful CPR, while some authors promote chest-compression-only strategies [12]. Customary compression devices are widely used in human medicine [13] and apply a standardized force, pressure or depth on the chest wall compressing the heart. In animal models standardization of inter-individual treatment is crucial to compare interventions, which make mechanical chest compression devices an ideal treatment option.

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Although a vast amount of literature exist for the use of mechanical chest compression devices in pigs and 38% of all pigs are resuscitated mechanically [11], certain limitations apply. Compression devices are set to apply pressure on a flat-human chest wall. With considerable anatomic difference the porcine anteroposterior chest diameter is usually much larger and shaped differently compared to humans, thus suboptimal compression with subsequently inconsistent hemodynamics may result. Thus, some groups rely on monitoring of manual chest compression with defibrillator feedback-systems [14].

Here, we hypothesize that standardized resuscitation is feasible and renders adequate hemodynamics and perfusion in 50–60 kg pigs, using a specifically designed resuscitation board for a pneumatic chest compression device (here: LUCAS® II, Physio-Control Inc).

2. Methods

Approval was obtained from Regierungspräsidium Freiburg (G-16/139). The study was carried out in accordance with the European Union's directive 2010/63/EU on the "Protection of Animals Used For Scientific Purposes" and its reporting complies with ARRIVE guidelines [15].

2.1. Anesthesia

10 Landrace-Hybrid pigs (59.2 ± 2.1 kg bodyweight) were included in the study. Animals were fasted overnight with free access to water. Sedation was initialized using intramuscular ketamine (20 mg/kg) and midazolam (0.5 mg/kg), and an intravenous access was installed. General anesthesia was induced using propofol (2 mg/kg). The trachea was intubated (7.5–8.0 ID low-pressure cuffed tube) and anesthesia was maintained by continuous infusion of propofol (4–6 mg/kg/h), fentanyl (10 μg/kg/h) and cisatracurium (0.7–1 mg/kg/h). Lung-protective, volume-controlled ventilation strategy (fraction of inspired oxygen, F_iO_2 0.21; tidal volume 6–8 ml/kg) was adjusted to achieve normocapnia ($etCO_2$ 35–45 mmHg). Pulse oximetry and electrocardiogram were installed for monitoring purposes.

2.2. Instrumentation

Vascular cannulation was implemented in sterile technique using ultrasound guidance. Access to carotid artery was achieved using a 4 Fr. 8 cm pulse contour cardiac output (PiCCO) catheter (Maquet, Germany) connected to a $PiCCO_2$ system (Maquet, Germany). Via a 8.5 Fr. introducer sheeth (Arrow, USA) a 7 Fr. pulmonary artery catheter (Arrow, USA) was advanced into the pulmonary artery. PiCCO indices were calculated to the individual porcine body surface area [16]. An echocardiography probe (6 T–RS, GE Vingmed Ultrasound AS, Norway) was placed in the mid-oesophagus, a phased-array probe (3S–RS, 1.5–2.5 MHz, GE Medical Systems, USA) was used for transthoracic echocardiography and arterial and mixed venous blood gas analyses were performed consecutively.

2.3. Resuscitation board

For our purposes, we designed and constructed a special resuscitation board to secure and optimize LUCAS® II (PhysioControl Inc., USA) pneumatic chest compression function. To meet our specifications, it was conceptualized to be adjustable to different anteroposterior and mediolateral chest diameters according to the individual pig's size (theoretically ranging from 20 to 100 kg). A draft was accomplished with

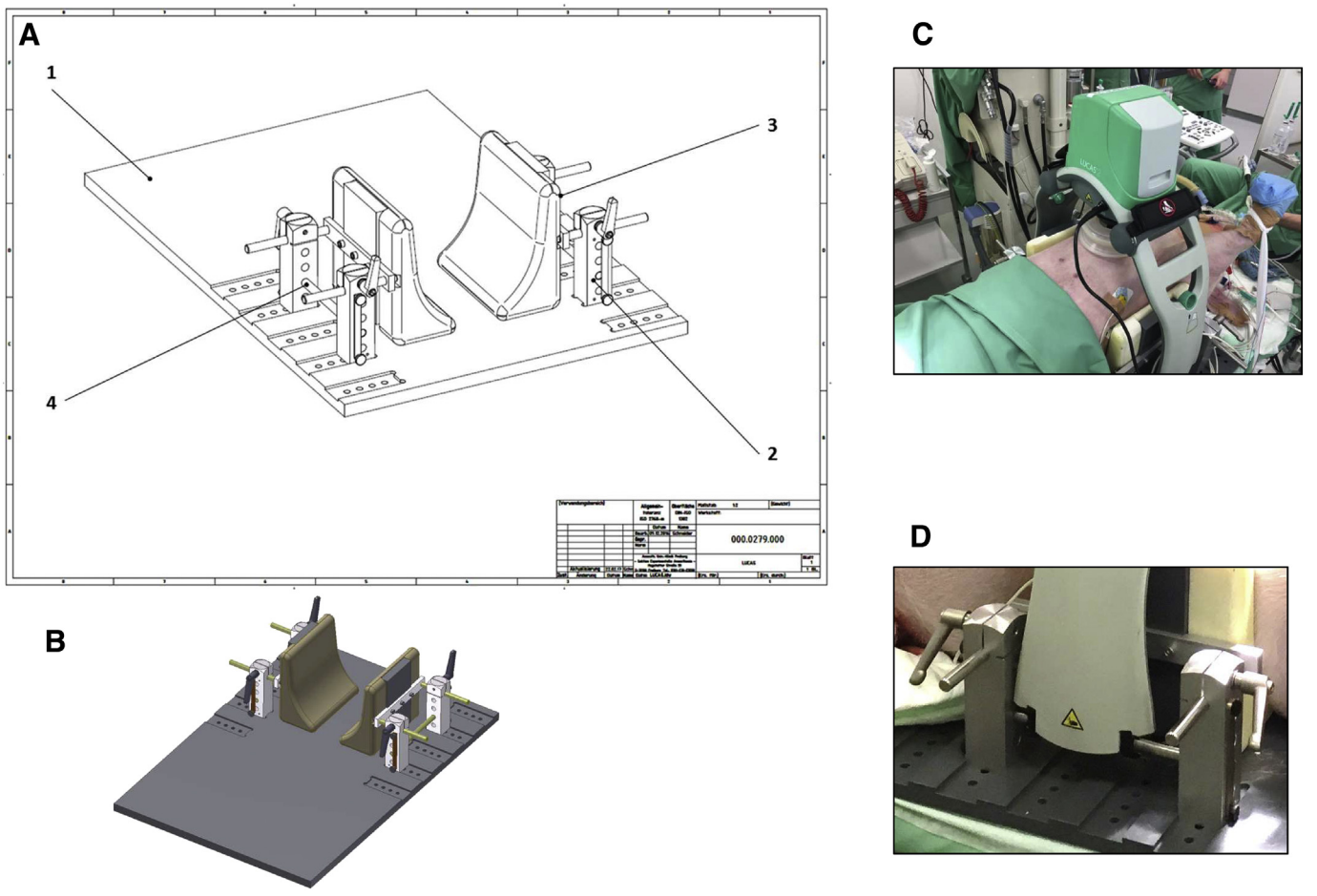

Fig. 1. (A) Construction of a resuscitation board for customary pneumatic-driven chest compression device (LUCAS®, PhysioControl), (B) Computer-aided design draft of resuscitation board, (C) Picture of resuscitation board with LUCAS® II and pig, (D) LUCAS®'claws fixed onto adjustable horizontal bar of resuscitation board.

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